Quantitative Chemical Mass Transfer in Coastal Sediments During Early Diagenesis: Effects of Biological Transport, Mineralogy, and Fabric --- Phase III

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LONG-TERM GOAL

The long-term goal of this study is to develop a better mechanistic and quantitative understanding of the effects of biologically enhanced transport, mineralogy, sediment fabric, and particle surface chemistry on biogeochemical reactions occurring in coastal sediments. Specifically, we plan to integrate quantitative expressions of the strongly coupled effects of bioirrigation, bioturbation, mineralogy, and sediment fabric on chemical mass transfer from field and laboratory mesocosm studies using numerical modeling.

OBJECTIVES

The short term objective during FY99 was (1) to achieve a better understanding of the bio-geologic dynamics of estuarine sediments by quantitatively describing the relationship between bioturbation, sediment physical properties, and permeability and (2) to accurately compute the permeability coefficient from two-dimensional images using Effective Medium Theory (EMT), and verify results with in situ, mesocosm and laboratory permeability measurements. Our hypothesis is that bioturbation will alter sediment microfabric and thus sediment permeability.

APPROACH

The approach is an integration of field sampling, controlled experiments in laboratory mesocosms, image analysis and numerical modeling. Experimental results are measured by laboratory analyses of bulk physical properties; macro/microscopic analyses of sediment fabric utilizing x-radiography; CT scanning and transmission electron microscopy; and permeability modeling using code based on Effective Medium Theory. This work is closely coordinated with Y. Furukawa, funded under Award # NOOO14-98-1-0200, who is analyzing pore fluids, bulk geochemistry and vertical distribution of ^{13}C; and P. VanCappellan (Georgia Institute of Technology) who is incorporating our results into the RT model, STEADYSED.

FY99 tasks included:

- Characterization of burrow networks, microfabric, and permeability for sediments populated with different types of infauna in laboratory mesocosms at NRL.
- Bimonthly field study of physical properties, microfabric, and burrow networks of burrowed nearshore sediments at St. Louis Bay and Mississippi Sound, Mississippi.

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- Field sampling and analyses at Sapelo field site in conjunction with GIT.
- Further development of techniques to image and quantify burrow and pore networks at various spatial and temporal scales.

WORK COMPLETED

- St. Louis Bay field studies are completed. Comparison with Sapelo Island field data is continuing.
- Initial mesocosm experiments with *Schizocardium* sp. (acorn worms) are completed. Experiments with *Hemipholis elongata* and *Ophiophragmus moorei* (brittle stars) has been initiated.
- Microfabric comparison between burrow walls, ejecta mounds of *Schizocardium* sp. and matrix sediment is completed.
- Model sensitivity study is completed.

RESULTS

- ***St. Louis Bay field studies.***

  Physical properties profiles from the open Sound site show the expected trends produced by sediment consolidation. Very high initial water-related values are attributed to bioturbation in the upper 12-15 cm. Physical properties trends from the grassy marsh sites lack the trends expected from consolidation processes and reflect the influence of other processes such as seasonal variation in water level and salinity, and the binding effects of marsh grasses. Trends of matrix sediment in the mesocosms (between burrows) reflect consolidation processes; water-related properties around the burrows (e.g., in ejecta mounds) are extremely high.

  Permeability measured in the aquaria with a miniaturized in situ probe reflects the influence of burrows. Tanks populated with 96 worms/m^2 have lower permeability (two orders of magnitude) than tanks with 800 worms/m^2 (figure 1). The main conclusion resulting from the St. Louis Bay and mesocosm studies is that fluid flow in heavily burrowed sediment is controlled by the burrows, and that permeability through the matrix sediment is insignificant when compared with the permeability of the entire sediment volume.
- ***Modeling results.***

  A sensitivity study of the EMT model to input parameters indicates that pore throat radius is the main variable controlling permeability, that is, the size of the smallest constricting passages has more effect than other variables. As the size of pore bodies increases, permeability decreases, probably because as the pore body size increases, the pore body must be filled before fluid flow is resumed. The coordination number (number of pore throats connecting pore bodies) is critical when the volume has few pore bodies. As the number of bodies increases, the influence of coordination number decreases. Use of the harmonic mean rather than the arithmetic mean produces permeability values closer to measured permeability values because the importance of the smaller pore spaces is emphasized.

- ***Microfabric analyses***

  Image porosity, analyzed using Image Tool shows the influence of bioturbation on water-related properties and permeability. Large differences in void space exist between burrow walls, ejecta mounds and matrix sediment (figure 2). In situ permeability using a miniaturized

in situ probe shows parallel trends in permeability and demonstrates permeability variability on the centimeter scale.

IMPACT/APPLICATION

A better understanding and mathematical description of biologically-enhanced transport, sediment fabric and particle surface chemistry during shallow diagenesis will allow us to better model and predict the fate and transport of solutes, particles and associated pollutants. By concentrating on fine-grained sediments over the next few years, we hope to make a significant contribution understanding harbor pollution solutions. In addition, by understanding the effect of fabric changes during diagenesis, we will be able to better predict sediment physical and geoacoustic properties of interest to the MCM community, (predicting mine burial in shallow coastal regions) and the acoustic community for modeling acoustic propagation.

TRANSITIONS

Techniques for quantitative characterization (2D and 3D) of sediment macro and microfabric will be transitioned to other ONR-funded programs including the High-frequency Sound Interaction in Ocean Sediments: Modeling Environmental Controls DRI. It is anticipated that results from this effort will contribute to applied environmental programs in the future.

RELATED PROJECTS

This project has leveraged the NRL 6.1 core program (Microenvironmental Studies) for support, particularly for the field effort, and will continue to do so. Microfabric results have been used in modeling efforts to predict permeability and will undoubtedly continue to benefit other programs with similar requirements, e.g., the ONR High Frequency Sound Interaction DRI will require quantitative pore space and particle geometry data for prediction of permeability and porosity.

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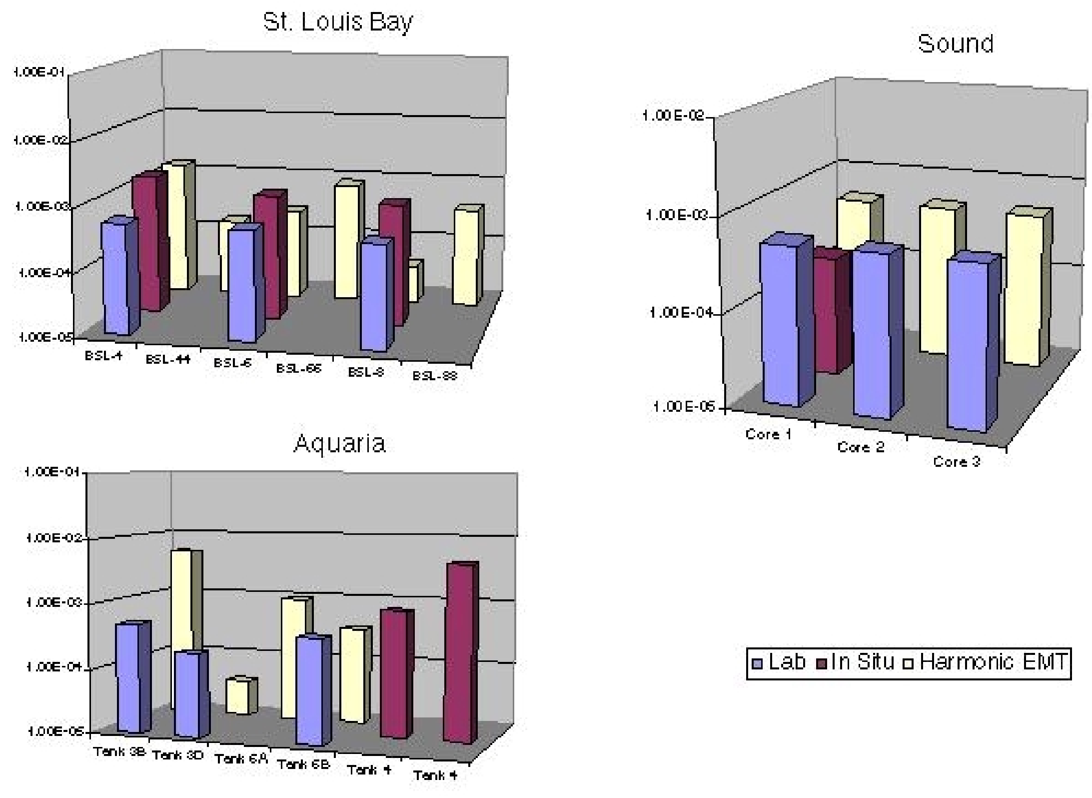

Figure 1. Comparison of permeability, measured in situ using the in situ permeameter, in the laboratory using a falling head method and modeled using EMT code, as a function of burrowing in St. Louis Bay, Mississippi Sound and laboratory aquaria.

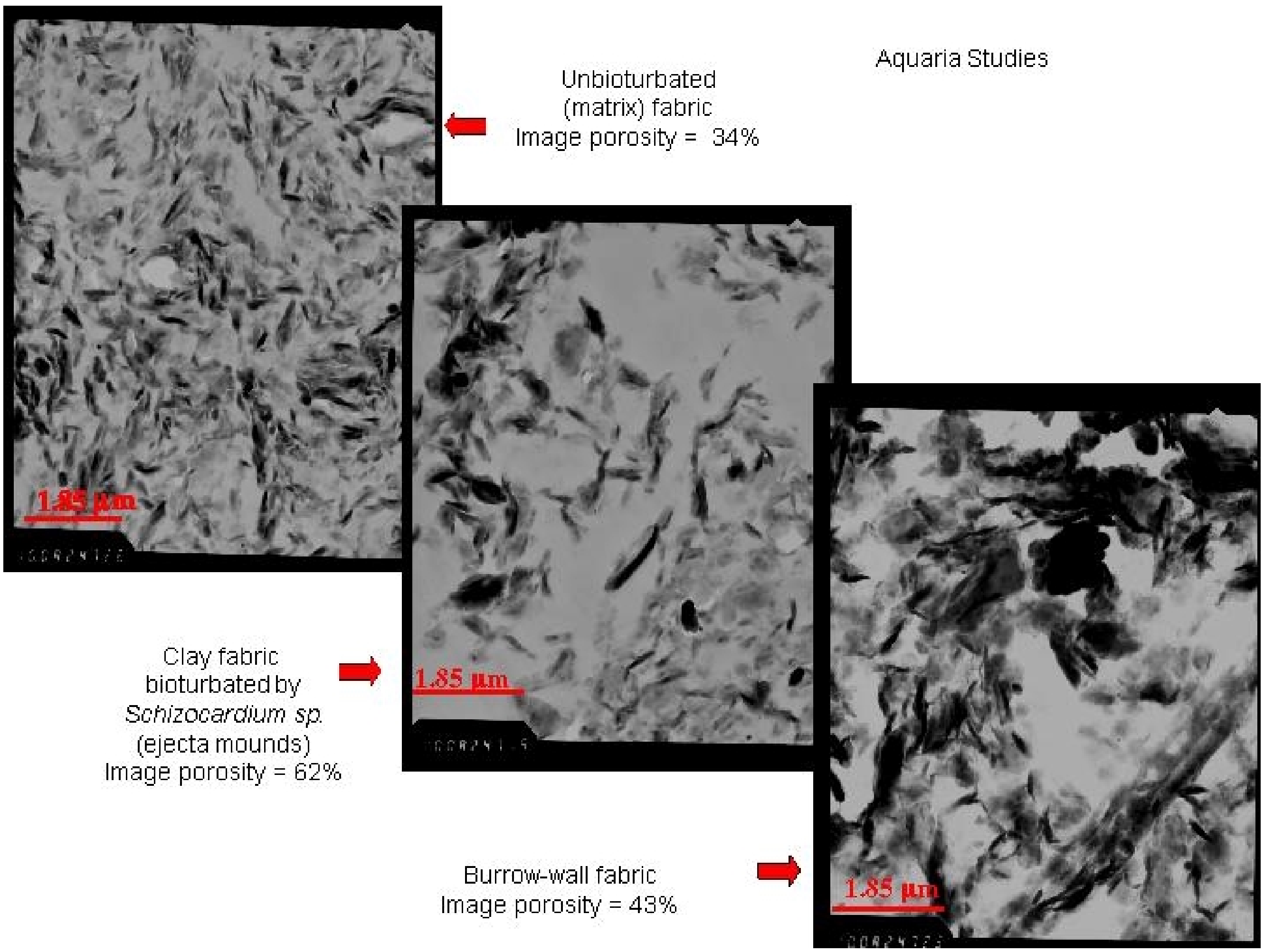

Figure 2. Image analysis of 2D microfabric shows significant differences in porosity between sediment in the undisturbed matrix, ejecta mounds and burrow walls.